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DETECTORS FOR SELECTIVE REGISTRATION OF CHARGED PARTICLES AND GAMMA-QUANTA

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Пропонується конструкція комбінованого детектора (КД) для одночасної реєстрації заряджених часток і γ-квантів. КД складається з монокристалічної платівки ZnSe(Te), яка розташована на вхідному вікні сцинтилюючого прозорого світловоду з CsI(Tl) та Al_2O_3(Ti) у вигляді зрізаної піраміди. Світловод з CsI(Tl) використовується для створення додаткового каналу реєстрації γ-випромінення, а також захищає фотодіод від впливу проникаючої радіації. Показано, що використання такого світловоду не погіршує енергетичні характеристики ZnSe(Te). Отримана роздільна реєстрація α-часток та γ-випромінення в умовах одночасного збудження ZnSe(Te) частками ^{239}Pu (R_α=6 %) и CsI(Tl) частками ^{241}Am (R_γ=20 %). Використання селективного оптичного фільтра дозволяє розділяти піки повного поглинання (п.п.п) у випадку їх взаємного накладення.

Предложена и описана конструкция комбинированного детектора (КД) для одновременной регистрации заряженных частиц и γ-квантов. КД состоит из монокристаллической пластинки ZnSe(Te), расположенной на входном окне сцинтиллирующего прозрачного световода из CsI(Tl) и Al_2O_3(Ti) в виде усеченной пирамиды. Световод из CsI(Tl) используется для создания дополнительного канала регистрации γ-излучения, а также защищает фотодиод от воздействия на фотоприемник проникающей радиации. Показано, что использование такого световода не ухудшает энергетические характеристики ZnSe(Te). Получена раздельная регистрация α- и γ-излучения при одновременном возбуждении ^{239}Pu (ZnSe(Te)) (R_α=6 %) и ^{241}Am (CsI(Tl)) (R_γ=20 %). Использование селективного оптического фильтра позволяет разделять пики полного поглощения (п.п.п) в случае их наложения друг на друга.

A new design is proposed and described of a combined detector (CD) for simultaneous detection of charged particles and gamma-quanta. The CD comprises a single crystalline plate of ZnSe(Te) placed onto the output window of a scintillating transparent light transducer made of CsI(Tl) and Al_2O_3(Ti) in the shape of truncated pyramid. The CsI(Tl) light transducer is used to create an additional channel for detection of gamma-radiation, as well as for protecting the photodiode from the penetrating radiation. It is shown that introduction of such light transducer does not worsen the energy characteristics of ZnSe(Te). Separate detection of alpha- and gamma-radiation has been achieved under simultaneous excitation by ^{239}Pu (ZnSe(Te), R_α = 6 %) and ^{241}Am (CsI(Tl), R_γ = 20 %). The use of selective optical filters allows separation of the peaks of total absorption (p.t.a.) in the case of their superposition.

INTRODUCTION

Combined detectors (CD) are combinations of several scintillators with different sensitivity to charged particles and gamma-quanta, as well as different pulse rise and decay times. CD can be used for simultaneous separate detection of these particles in modern radiation spectrometers based on silicon photodiodes or PMT. A possibility was shown in principle [1] to separate signals from "sandwich" type detectors composed of ZnSe(Te) and CsI(Tl) using the technique of taking signals from several outputs of the detection block that differ by the signal duration. When scintillator combination ZnSe(Te) and CWO were used with Si-PIN-PD [2], separate detection was achieved for α-peak of energy E_α=5.15 MeV (by ZnSe(Te) crystal) and γ-peak of 4.13 MeV energy (by CWO crystal). However, in these works satisfactory spectrometric resolution of the detected radiation has not been achieved.

In the present work, the problem was to be solved of spectrometric separation of signals from charged particles and gamma-quanta by means of the use of CD, which comprises a CsI(Tl) scintillator in the shape of a polyhedral truncated pyramid as light transducer and detector of gamma-quanta, and a ZnSe(Te) scintillator

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plate as detector of charged particles, located on the truncated top side of the pyramid. We have also carried out preliminary studies of CD in which a truncated pyramid made of ticor was used as light transducer.

The use of ZnSe(Te)-based scintillators is due to their high spatial resolution $R_{\alpha,e}$ = 3-6 % both with alpha-particles of E_α = 5.15 MeV and electrons of E_e=0.976 MeV [3]. CsI(Tl) crystals have energy resolution R_γ ~ 6 % at E_γ = 0.662 MeV, peak to valley ratio for ^{60}Co reaches 15, and they can be used as gamma-radiation detectors. Scintillators ZnSe(Te) and CsI(Tl), besides this, are distinguished by their high light output. For CsI(Tl) single crystals, the light output can be as high as $5.5 \cdot 10^4$ photons/MeV; for ZnSe(Te), depending on preparation technology of either "fast" or "slow" scintillators, this value can vary from $4.0 \cdot 10^4$ to $7.8 \cdot 10^4$ photons/MeV [4]. The α/β ratio is 1.0 for ZnSe(Te) and 0.4-0.6 for CsI(Tl).

RESULTS

The combined detector tested was a truncated pyramid of CsI(Tl), with 40 mm height and area of the input and output windows 5×5 mm^2 and 15×15 mm^2, respectively. Upon the output surface of the crystal, a ZnSe(Te) plate of 5×5×0.8 mm^3 was placed. "Fast" ZnSe(Te) crystals were used, with decay time constant of 3-10 μs. Such crystals are characterized, as compared with "slow" ZnSe(Te) crystals, by improved energy resolution R_α when irradiated with α-particles. The size and shape of the truncated pyramid were chosen accounting for Monte Carlo calculations carried out to determine conditions of the optimum light collection from the output crystal surface. It has been shown [5] that light transducers of the shape of tetrahedral pyramid yield the light almost two times better than parallelepiped-shaped ones. Increase in number of the pyramid sides does not contribute substantially to the light collection coefficient.

Measurements of spectrometric characteristics were carried out both with photodiodes and PMT. For measurements with photodiode, we used a Hamamatsu Si-PIN-PD of S-3590 type in combination with a charge-sensitive preamplifier (CSPA) and a standard amplifier-shaper of 1101 type. Spectrometric studies were carried out using a multi-channel analyzer based on a Notebook Pentium PC and an analog-to-digitconverter (ADC) with original software [1]. In measurements with PMT, we used a R1307 type PMT with 3 in photocatode diameter. The light output and amplitude resolution were determined using a standard spectrometric circuit, comprising a BUS2-94 preliminary amplifier and a multichannel pulse amplitude analyzer of AMA-03-F type.

The main parameter characterizing the possibilities of a specified CD for separate detection of gamma-quanta and charged particles is the value of its α/γ ratio

$$\delta_{\alpha/\gamma} = \frac{E_\alpha}{V_\alpha} \cdot \frac{V_\gamma}{E_\gamma},$$

where E_α and E_γ are energies of alpha-particles and gamma-quanta, respectively; V_α is the pulse amplitude under alpha-excitation by ZnSe(Te) plate, V_γ is the pulse amplitude under excitation by CsI(Tl) truncated pyramid.

This value was determined by the line set in the radiation spectrum of ^{226}Ra γ-quanta and α-particles. For the CD under study, α/γ value was 0.15-0.25, depending upon the light output of both scintillators and the time constant of the integrating chain. In addition, the α/γ value could be varied by placing a selective optical filter between the PMT photocathode or PD and the CD output window, which allowed non-proportional changes in light output from different scintillators.The use of truncated pyramid-shaped scintillators as light transducers does not worsen the energy characteristics of ZnSe(Te) scintillators. The R_α value for the plate placed directly onto the PD or onto the truncated top of the CsI(Tl) pyramid is not changed and is ~ 6 %. A similar situation was also observed for detection using PMT.

Fig.1 shows the pulse amplitude spectrum of the studied CD under simultaneous irradiation by ^{239}Pu α-particles (ZnSe(Te)) and ^{241}Am γ-quanta (CsI(Tl)) , measured using PMT. Resolution is observed of spectrometric peaks of total absorption (p.t.a.) due to γ-quanta (R_γ = 20 %) and α-particles (R_α = 6 %).

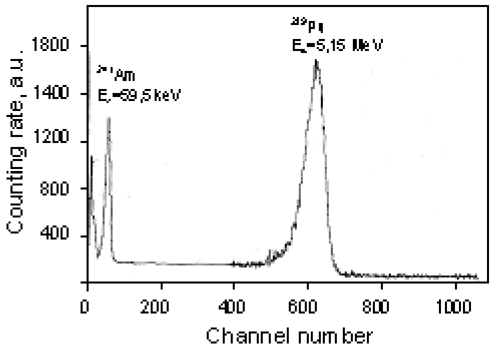

Fig.1. Spectrum ^{239}Pu α-partiecles and ^{241}Am γ-quanta, obtained using CD with R1307 PMT

Under irradiation by ^{137}Cs γ-quanta of energy E_γ =0.662 MeV and ^{239}Pu α-particles the total absorption peaks are superimposed (Fig.2a). Their separation became possible with the help of a selective optical attenuator that non-proportionally decreases the light output values of CsI(Tl) and ZnSe(Te). Fig.3 shows luminescence spectra of scintillators CsI(Tl) (curve 1), ZnSe(Te) (curve 2) and the spectrum obtained with the selective filter (curve 3). As a result of the use of such optical filter, signals from detected α-particles and γ-quanta are separated (Fig.2b).

Fig.4 shows the pulse amplitude spectrum from the deposited ^{241}Am sample obtained using CD. As it can be seen, γ-quanta and α-particles from such a source are resolved satisfactorily.

As another material for CD light transducer, we also used ticor (α-Al_2O_3:Ti^{3+}) crystals. Ticor single crystals have luminescence spectrum (λ_{max} = 790 nm) at longer wavelengths as compared with CsI(Tl) and ZnSe(Te), decay times τ = 3.0 – 5.0 μs, and low effective atomic number Z_{eff} = 12. In addition, this scintillator has the highest thermal and chemical stability among those used by us, and the use of this scintillator is promising for works in liquid fuel-containing media.

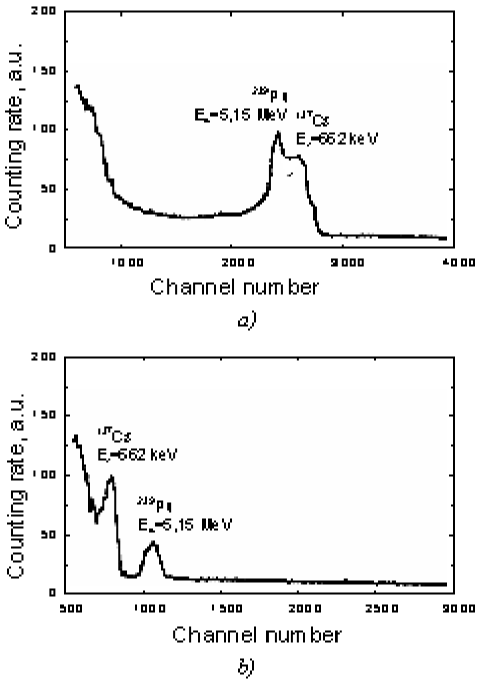

Fig.2. Spectrum of ^{239}Pu α-partiecles and ^{137}Cs γ-quanta without (a) and with (b) the selective optical filter

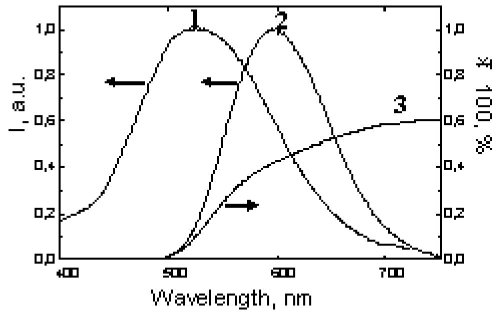

Fig.3. Luminescence spectra of scintillators CsI(Tl) (1) and ZnSe(Te) (2), and transmission spectrum of the filter used (3)

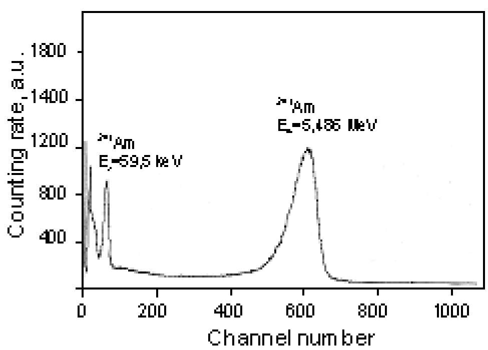

Fig.4. Spectrum ^{241}Am α-partiecles and γ-quanta, obtained using CD with R1307 PMT

Preliminary studies of CD that comprised a ticor scintillator as light transducer in the shape of truncated pyramid and a plate of ZnSe(Te) have shown that separate detection with such CD is possible only for alpha-particles (ZnSe(Te)) and electrons (ticor). Detection of gamma-quanta using ticor is not efficient due to its low Z_{eff}. More careful studies of such CD for separate detection of α-particles and electrons is planned for the future. Besides this, ticor crystals can be used as protection shields- light transducers for solid-state photoreceiving devices.

The proposed CD design can be used for construction of a multi-detector system in the form of "Crystal-Ball" for 4π-geometry detection of α- and γ-radiation of "hot" particles. The measurement results have shown that the number of sides of the truncated pyramid does not affect the R_α value, which opens broad possibilities of using penta- and hexagonal pyramids for the "Crystal-Ball" construction [6]. Varying the scintillator material in the CD design, it is possible to separately detect nearly all types of ionizing radiation, including light and heavy charged particles, gamma-quanta and neutrons.

CONCLUSIONS

As a result of the work performed, a possibility has been shown for creation of a new type of combined detectors, which ensure separate simultaneous detection of alpha- and gamma-radiation and do not require the use of complicated electronic circuits for separation of signals from light and heavy particles.

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